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# Dosimetric image reconstruction in eye brachytherapy using silicon pixelated detectors

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## Abstract

This study presents a high spatial resolution dosimetry system for quality assurance of I-125 eye plaques. The system is based on a silicon pixelated detector and is capable of deriving 3D dose. A simple design was implemented, incorporating a movable eye plaque in a small water phantom above the silicon Medipix detector. It is suitable for obtaining 2D planar dose images at different depths in water, for subsequent reconstruction. The effect of backscattering of a medium placed on the back of the Medipix has been studied in terms of dose distribution. Additionally, event counting mode on the detector was compared to the more complex time-over-threshold mode and the TG-43 protocol for determining its suitability in dosimetry.

**Keywords:** eye plaque, brachytherapy, dosimetry, Timepix, Medipix, Iodine-125

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## 1. Introduction

Intraocular tumours, whilst having a five in a million occurrence, pose a significant risk to sufferers (Lutz et al., 1999). Typically, tumour treatment may involve resection of the surgical mass or, for progressed tumours, the eye may be enucleated (Shields and Shields, 2009). The most widely used treatment for posterior uveal melanoma, however, is radiotherapy, especially in medium or large tumours (Shields and Shields, 2009). Of the radiotherapy treatments used, brachytherapy is generally the preferred method. This is because its major alternative, proton therapy, has relatively high costs and lacks widespread accessibility.

Eye brachytherapy involves the treatment of ocular malignancies through the use of radioactive sources within an eye plaque. Typically the sources are I-125 or Pd-103 for brachytherapy seeds and Ru-106 for uniformly coated plaques. Presently, the TG-43 Protocol is used as an industrial standard for determining the dose from brachytherapy sources (Rivard et al., 2004). While treatment planning software (TPS) is sometimes used prior to treatment, there are currently no quality assurance (QA) techniques for customised plaques that take into account the complex sensitivities of the treatment. Some of these geometric factors include tumour size, shape, location and the proximity to vital areas in or around the eye. Critical structures such as the optic nerve and macula may undesirably receive up

to 85% and 58% of the prescribed dose for the tumour, respectively (Wu, 1990).

Pre-treatment 3D dosimetry of the eye plaque will provide an improvement to the level of QA for eye brachytherapy. Pixelated, silicon detectors may be used in the development of a QA system for eye plaque brachytherapy. Detectors such as the Medipix 2 (Llopart et al., 2002) and its successor, the Timepix (Llopart et al., 2007), provide many capabilities and hence form a robust platform for preliminary research (Jakubek, 2007). The Medipix 2 is a 65k pixel readout chip with the ability to operate in event counting mode. In addition to the functionality provided by the Medipix 2, the Timepix is capable of measuring time-over-threshold (TOT), which reveals charge deposition per pixel on an event by event basis, and time of arrival.

The verification of the 3D dose distribution within the eye predicted by the TPS for customised eye plaques is important due to the variability in the activity of seeds and possible error in seed placement in the plaque. This study aims to improve the clinical QA for brachytherapy treatment of ocular malignancies through the research and development of a treatment plan evaluation system.

## 2. Methods and Materials

One aim of this study was to investigate the effect of backscattering from the material downstream of the detector to better understand the design for a QA system for eye plaque dosimetry. The other aim was to investigate whether the event counting operation of the Medipix 2 is significantly similar to the spectroscopy mode (TOT) of the Timepix for I-125 dosimetry. By providing the total

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Figure 1: Schematic diagram of the 15mm ROPES eye plaque insert, showing the seed layout. All ten seed slots were filled with Iodine-125 seeds in this investigation.

integrated charge generated in each pixel, the operation of the Timepix in TOT mode is similar to that of an electrometer. Previously, we established that spectroscopic dosimetry is possible in I-125 seed dosimetry in prostate brachytherapy (Cutajar et al., 2006).

### 2.1. Eye phantom dosimetry with the Medipix

We demonstrated earlier that 3D dose distributions within an eye phantom can be obtained by reconstructing data taken from successive measurements of planar doses at different depths (Weaver et al., 2010). To achieve this, the position of the Medipix detector was changed within a layered eye phantom while the plaque was fixed to the phantom's surface. This method was laborious due to the many acquisitions and sensitive phantom alignment and it only allowed for discrete distances for measurements.

### 2.2. Plunging water phantom

In a current studies, we are investigating the feasibility of an automated system for fast 3D dose reconstruction for eye plaques using a water phantom with the Medipix detector placed below (see Figure 2). This system uses a "plunger" to move the eye plaque and a virtual eye through a small, cylindrical water phantom,  $100\text{mm} \times \varnothing 29.5\text{mm}$  in size. In contrast to the previous method, in the present system the Medipix is stationary and the plaque moves through water.

Fixing the plaque to a mechanism allowed for fine control of the plaque's position relative to the detector. It was translated along a vertical axis which was both normal and central to the detector surface. A water filled vessel (the phantom) was placed as close as allowable to the top of the detector. The plaque was immersed within the water and measurements were taken at discrete intervals between the beginning and final position of the plaque's motion, during which, the water level remained constant. Initially, the plaque was zeroed at the closest possible point to the detector within the phantom.

This study used a 15mm ROPES eye plaque (See Figure 1) with 10 Iodine-125 seeds (Oncoseed: Model 6711, Oncura (2005)). The seeds had activities of  $0.06\text{mCi}$  and  $0.39\text{mCi}$  for the backscatter experiment and the charge/event counting experiment respectively. Both investigations used the same arrangement of apparatus (see Figure 2) for detector readout and plaque placement. One stage

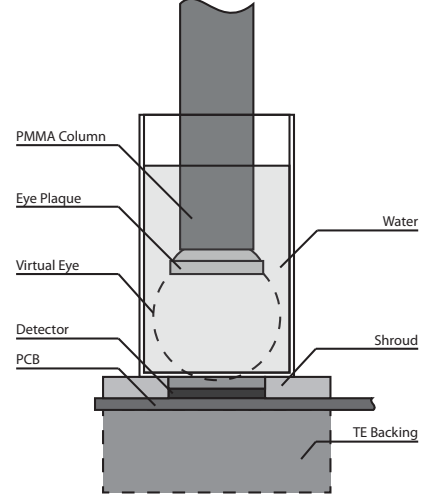


Figure 2: A schematic representation of the apparatus configuration including the detector placement below a water filled vessel and the tissue equivalent (TE) backing (CIRS Incorporated, 2010).

of the backscatter investigation included the placement of a block of water equivalent material (Plastic Water<sup>®</sup> LR, CIRS Incorporated (2010)) below the detector. In this case the same measurements were taken with different scattering conditions to account for the tissue surrounding and including the eye. This study aimed to measure the effect a lack of backscattering material behind the detector had on dose perturbation since the TG-43 calculations assume infinite scattering material.

### 2.3. Count and Charge Measuring

This section of the study aims to compare event counting mode using energy windows to both the TOT mode and the TG-43 protocol. The eye plaque was positioned and both count and TOT measurements were taken using the Timepix, eliminating any error in distance between them. Due to the dominance of  $27\text{keV}$  photons in the I-125 spectrum, hardening is not significant and hence the spectrum does not change significantly with depth. Considering this, dosimetry system based on the Medipix 2 design could be developed at a lower cost than would otherwise be possible with the more complex Timepix system.

The data collected from the detectors consisted of a  $256 \times 256$  square array of values for each distance and mode. Each acquisition was taken over a period of 500s which was composed of the integration of  $500 \times 1\text{s}$  acquisitions which was sufficient to prevent counter overflow. To generate the depth-dose curve for analysis, a  $10 \times 10$  sample of the 65k pixels was used. This sample was taken through the centre of each of the matrices; these values were then averaged. Each pixel has a pitch of  $55\mu\text{m}$ , giving the averaged region an area of  $0.55 \times 0.55\text{mm}^2$ . These points were then used to generate the required depth dose curves for comparative analysis.

### 3. Results and Discussion

Two sets of depth-dose curves were generated for a comparison between event counting, charge measurement and the TG-43 protocol and for the investigation of the effect of backing material. The data presented in the following graphs has been normalised at the closest available point to  $10\text{mm}$ , as practised in the TG-43 formalism (Rivard et al., 2004).

#### 3.1. Energy and event counting

In order to make a comparison between TOT mode, event counting mode and the TG-43 protocol, three sets of data have been plotted in Figure 3. The TG-43 protocol cannot be extrapolated for points of interest less than  $5\text{mm}$  from the seed, as such it has not been plotted in Figure 3. It is, however, advantageous for dose verification in this region as it may include the optic nerve or other vital structures that should be spared.

The error associated with the number of event counts is less than  $0.9\%$  for distances  $9.9\text{mm}$  or less. Figure 5 illustrates that the differences between the event counts and the TOT values do not exceed  $1\%$  when normalised at  $9.9\text{mm}$ . A comparison of both the event counting and TOT data with the TG-43 protocol shows that they are in good agreement with one another. The slight discrepancies between the measured data and the TG-43 curve can be explained due to differences in the geometries. The TG-43 protocol assumes that the seeds are surrounded by an infinite amount of water while the apparatus did not incorporate material for back or side scattering. Additionally, the experimental apparatus included the use of the plaque's stainless steel cover while the TG-43 did not.

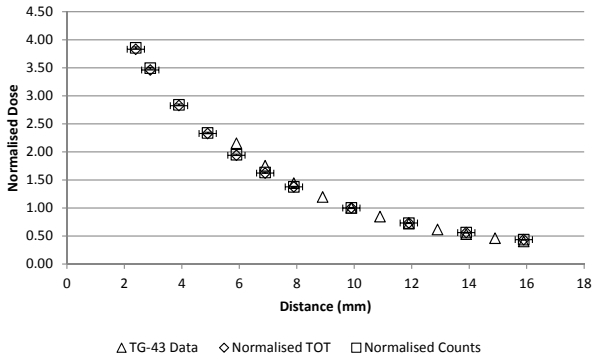


Figure 3: The depth-dose curve of both number of events and the total energy of events over 500s intervals. The source was a  $15\text{mm}$  ROPES eye plaque with ten I-125 seeds

#### 3.2. Effects of backscatter

The two sets of data displayed in Figure 4 are the average number of events both with and without backing material present in the central  $10 \times 10$  pixels of the detector for each distance observed. Errors in the event count

datasets are  $\pm 0.3\text{mm}$  in distance and range from  $0.49\%$  to  $1.29\%$  and  $0.50\%$  to  $1.30\%$  with and without backing material respectively. The percentage increase of the number of counts with the addition of backing material is displayed in Figure 5.

From the rightmost point in the square dataset of Figure 5 the values monotonically increase to a maximum  $6.71\%$  at  $5.19\text{mm}$  and then decrease again at closer distances. This near exponential decrease for distances larger than  $5.19\text{mm}$  is due to the short range of backscattered radiation from the I-125 seeds. As this maximum value is more than three standard deviations ( $1.78\%$ ) from the data set without backing, a significant difference exists between the two cases. At closer distances this increase is not as great due to the dominance of pre-existing backscattering through the silicon detector and PCB. In practical dosimetry, the detector should be used in conjunction with a water equivalent material.

Further study into the geometry of the vessel used for the water phantom should also be undertaken to investigate side scatter. The effect of the water level above the plaque could be investigated to consider the backscattered radiation from the brain, however, due to the stainless steel plaque cover, it is not likely to have a significant effect.

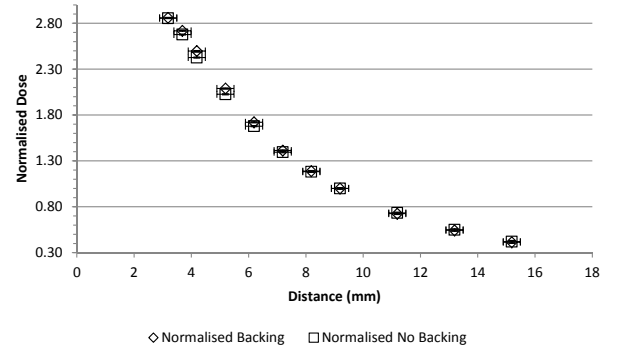


Figure 4: The depth-dose response of a  $15\text{mm}$  ROPES eye plaque with and without the presence of a tissue equivalent block of Plastic Water<sup>®</sup> below the detector. The central  $10 \times 10$  pixels of the Medipix were averaged for each depth measured.

### 4. Conclusion

From the similarities observed in the depth-dose responses of the backing investigation, it can be seen that additional backing material placed below the detector significantly influences the dose received in the eye phantom. While further investigation into the optimisation and effects of the scattering material should to be undertaken, it is clear that a practical dosimetry system should include water equivalent material below the detector.

The TOT and count mode data depicted in Figure 3 demonstrate significant similarities to both each other and the TG-43 protocol. The development of a dosimetry system based on the Medipix 2 would be a cheaper and sim-

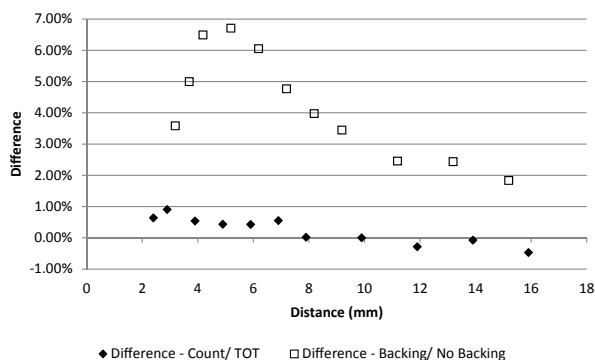


Figure 5: The dose increase with the addition of backing material is depicted in the square dataset. The percentage difference of event data from TOT data is depicted in the diamond dataset.

pler alternative to one based on the spectroscopic capabilities of Timepix. This is possible because the spectra of I-125 will not change considerably with depth. Further research in this field will involve the investigation of customised pixelated detectors and the required resolution for dosimetry measurements in eye brachytherapy.

The development of a fast, 3D dosimetry system for eye brachytherapy is possible with the required improvements studied in this investigation. This body of work will not only aid the development of QA techniques for eye brachytherapy but will also provide a base for radiotherapy applications such as prostate brachytherapy.

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